How To Use a Multimeter

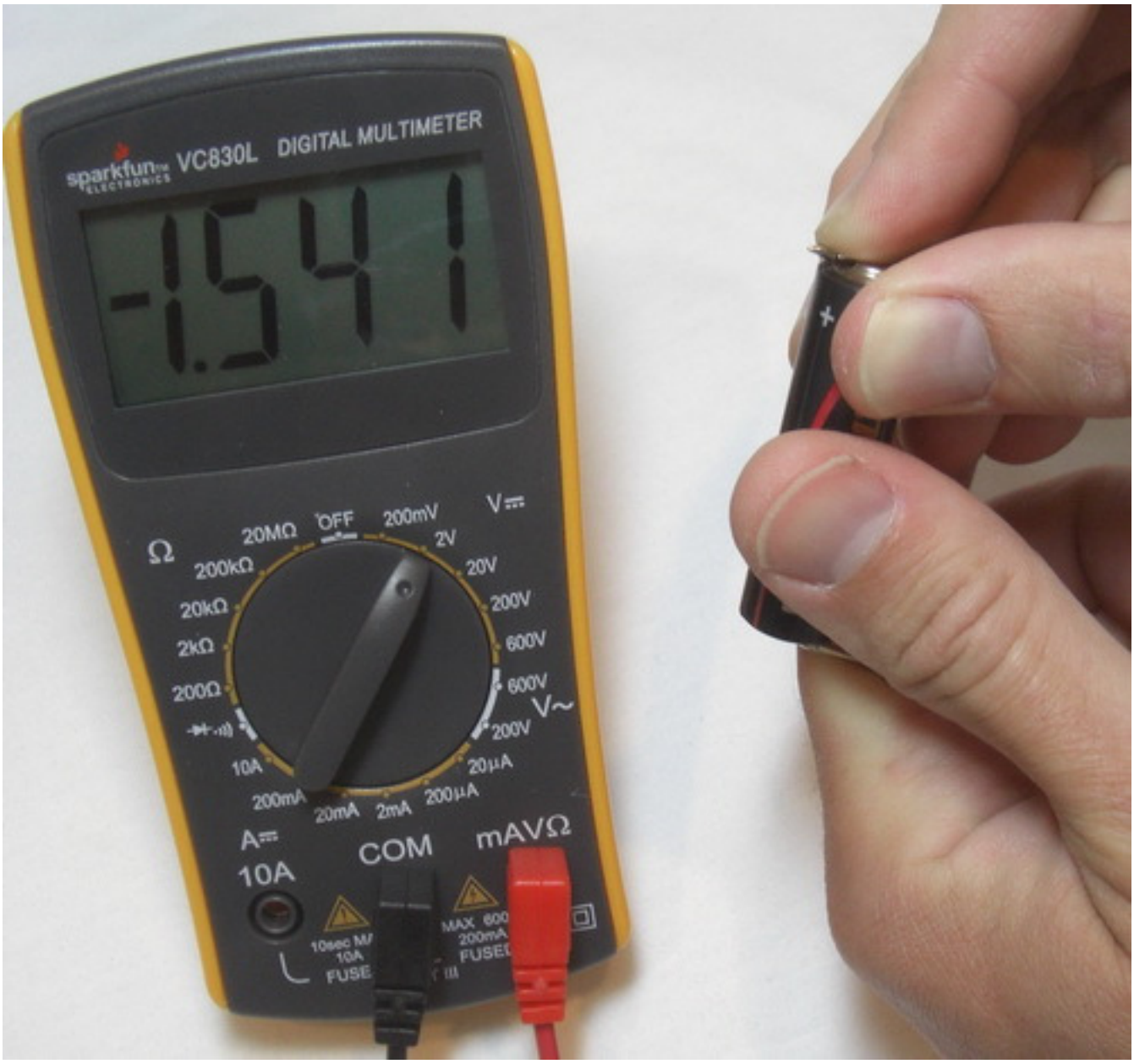
Wait, how do I use a multimeter? This is a common question for beginners and I am surprised by my own assumptions that people 'just know' how to use one. I even remember floundering in engineering school when they gave us no direction at all. So in an attempt to remedy this missing link, I hope this tutorial shows you the basics. For this tutorial we will be using the SparkFun VC830L. I've looked long and hard for a good, low-cost multimeter and the VC830L is everything I need in a day-to-day multimeter.

Multimeters are a tool that we use to measure multiple characteristics of electronics. Hence the 'multi'-'meter' (multiple measurement) name. The most basic things we measure are voltage and current. I use a multimeter for some basic sanity checks and some rough measurements. Is the regulator outputting 5V? If the regulator is outputting 4.2V instead of 5V, then possibly the input voltage is not high enough. Perhaps something else is wrong? Put a meter on it! The multimeter is your first defense when troubleshooting a system.

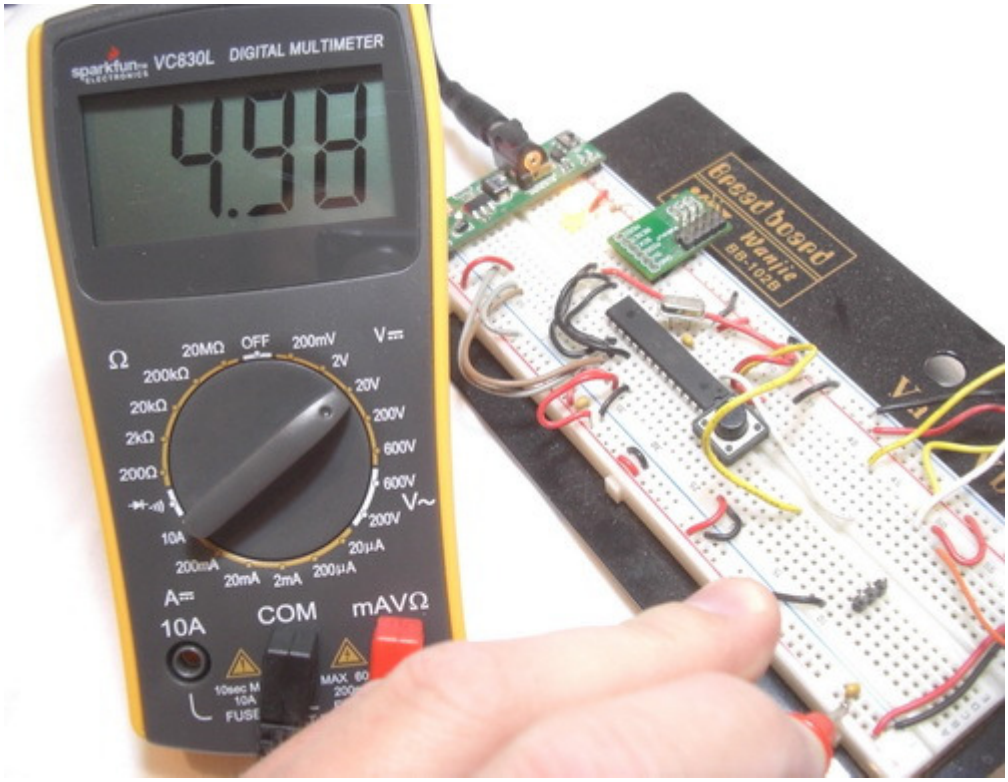
What does DMM stand for? It's just another name for digital multimeter (DMM).

How to Measure Voltage

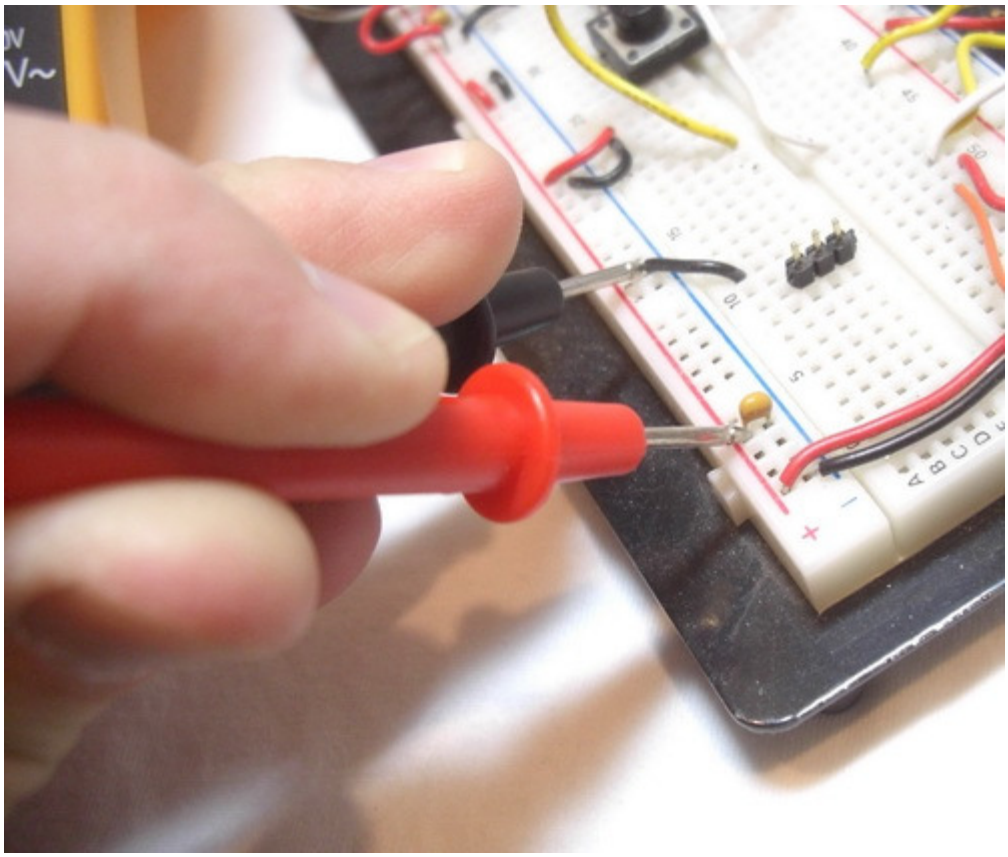
To start with something simple, let's measure voltage on a AA battery: Pull out your multimeter and plug the black probe into **COM** ('common') jack and the red probe into **mAVΩ**. Set the multimeter to "2V" in the DC range (DC is a straight line, AC is the wavy line). Squeeze the probes with a little pressure against the positive and negative terminals of the AA battery. The black probe is customarily connected to ground or '-' and red goes to power or '+'. If you've got a fresh battery, you should see around 1.5V on the display!



What happens if you switch the red and black probes? Nothing bad happens! The reading on the multimeter is simply negative - so don't worry too much about getting the red or black probe in the right place. I've gotten used to just sticking the probes where I have a problem circuit - I don't really notice whether the reading is negative or positive.

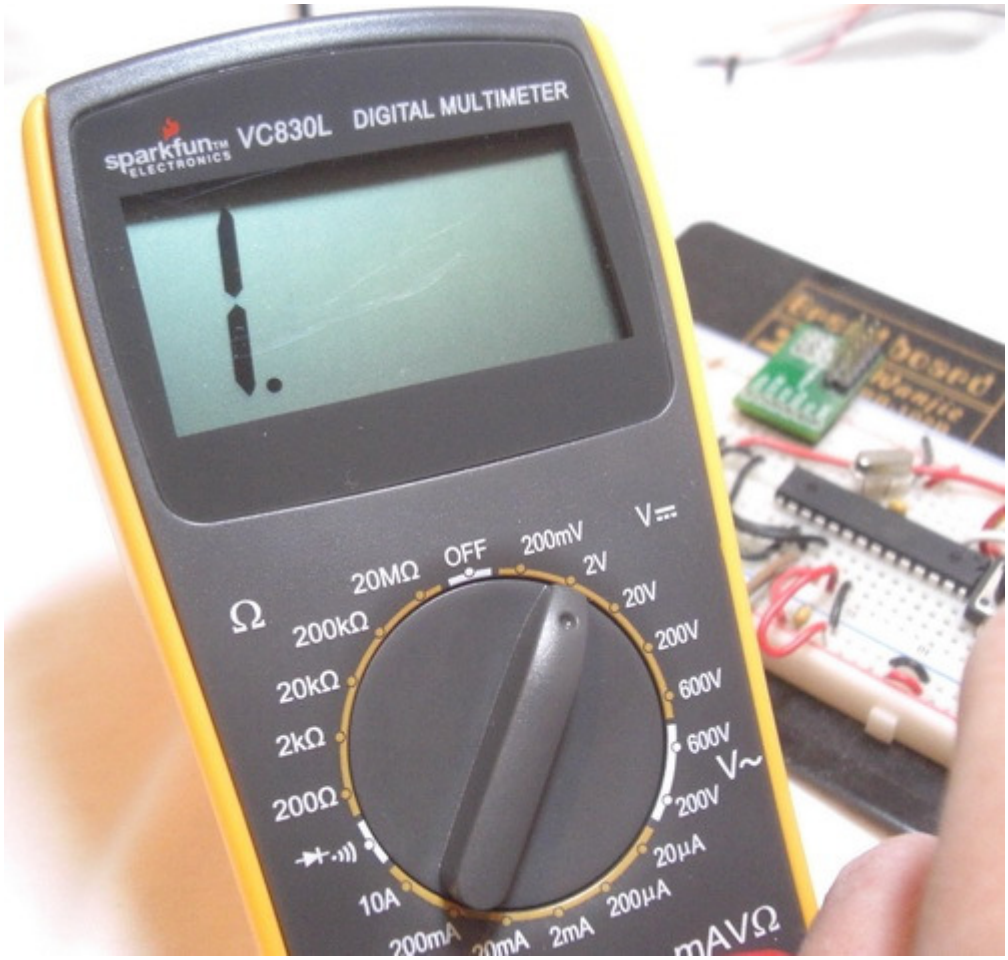


Now let's measure voltage on a breadboard or on a device: Set the knob to "20V" in the DC range (the DC Voltage range has a V with a straight line next to it). With some force (imagine poking a fork into a piece of cooked meat), push the probes onto two exposed pieces of metal. One probe should contact a GND connection. One probe to the VCC or 5V connection:



Now why did we set the multimeter to the 20V DC setting? Multimeters are generally not *autoranging*. You have to set the multimeter to a range that it can measure. For example, **2V** measures voltages up to 2 volts. **20V** measures voltages up to 20 volts. So if you've measuring a 12V battery, use the 20V setting. 5V system? Use the 20V setting.

What if you set it to the wrong range? Don't worry, nothing bad will happen. If you try to use the 2V setting to measure a 3.7V LiPo battery, you will probably see the meter screen change and then read '1'.



This is the meter trying to tell you that it is overloaded or out-of-range. Whatever you're trying to read is too much for that particular setting. Try changing the multimeter knob to a different range.

Why does the meter knob read 20V and not 10V? I believe this weird limitation is pretty standard on DMMs. If you're looking to measure a voltage less than 20V, you turn to the 20V setting. This will allow you to read from **2.00** to **19.99**. But why 20.00V and not 10.00V? It has to do with the number of segments the manufacturer has to build into the LCD. '1' takes two segments as the first/most significant digit. To display '2', you need (nearly) a full 7-segment display. It's cheaper to build a more simple display, so the first digit on many multimeters is only able to display a '1' so the ranges are limited to **1**9.99 instead of **9**9.99. Hence the 20V max range instead of 99V max range.

Note: There are fancy multimeters that are autoranging, meaning they automatically change their internal range to attempt to find the correct voltage, resistance, or current of the thing you're poking at. Set the knob to 'Voltage' and forget it. I've used an autoranging meter once or twice and, while it was fancy, it unfortunately just annoyed me. Because some readings can fluctuate quite quickly, the autoranger can get confused, quickly switching between the 20mA mode and 200mA mode trying to figure out what is going on. I prefer the manual mode multimeters. (high-end bench models often have a 'manual' mode to overcome this problem).

Warning: I generally stick to DC circuits (the settings on the multimeter with straight lines, not curvy lines). Most multimeters can measure AC (alternating current) systems, but I don't mess with them. It scares me every time I need to check a wall outlet. AC or 'main voltage' is the stuff that can zap you pretty good. I VERY carefully respect AC. If I need to measure it, I double check everything. Really the only times I've needed to measure AC are when I've got an outlet that is acting funny (is it powered?), or if I'm trying to control a heater (such as a hot plate).

How to Measure Resistance

I have to admit, I don't know how to read the color codes on a resistor. I know, BAD ENGINEER! But the online calculators are so easy to use! But if you don't have internet access, a multimeter is also handy at measuring resistance. Set the multimeter to the 20kΩ setting and hold the probes against the resistor legs.

The meter will read one of three things, 0.00, '1', or the actual resistor value. If the meter reads 9.90, well then you've got a 9.90k Ohm (Ω) resistor (remember you are in the 20kΩ mode, so you need to move the decimal three places to the right or 9,900 Ohms).

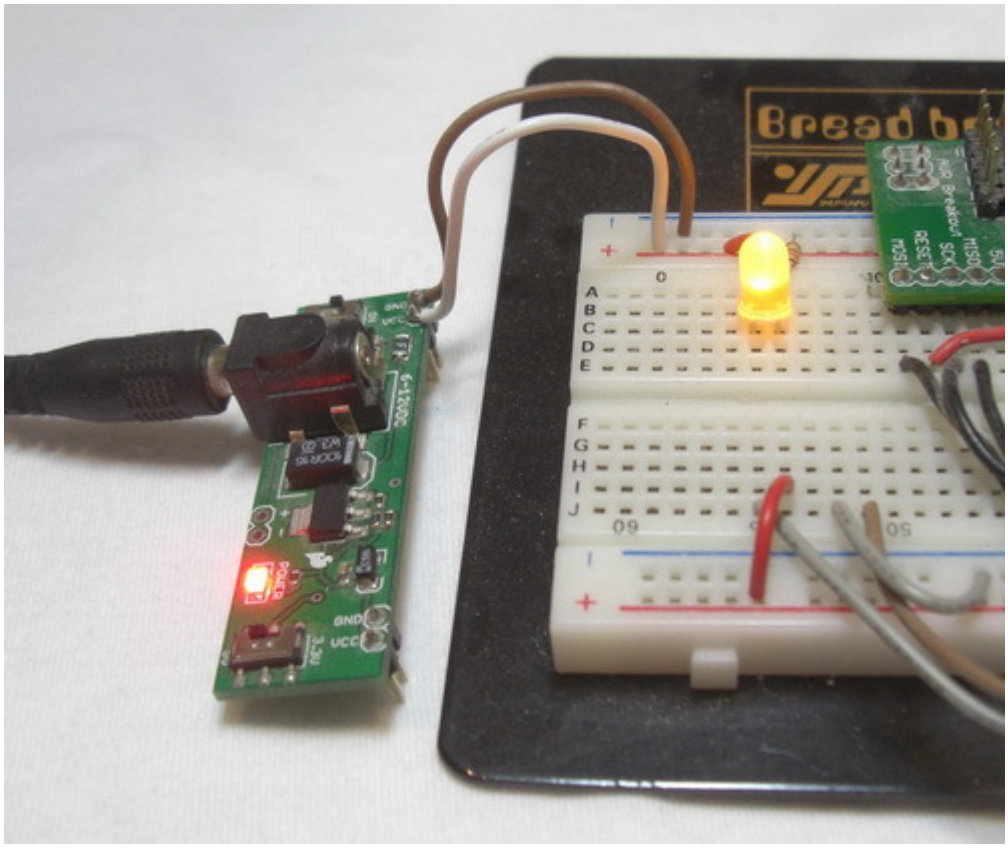
Remember that many resistors have a 5% tolerance. This means that the color codes may indicate 10,000 Ohms (10kΩ), but because of discrepancies in the manufacturing process a 10kΩ resistor could be as low as 9.5kΩ or as high as 10.5kΩ. Don't worry, it'll work just fine as a pull-up or general resistor.

If the multimeter reads '1', it's overloaded. You will need to try a higher mode such as **200kΩ** mode or **2MΩ** (megaohm) mode. If the multimeter reads 0.00 or there abouts, then you need to lower the mode to **2kΩ** or **200Ω**.

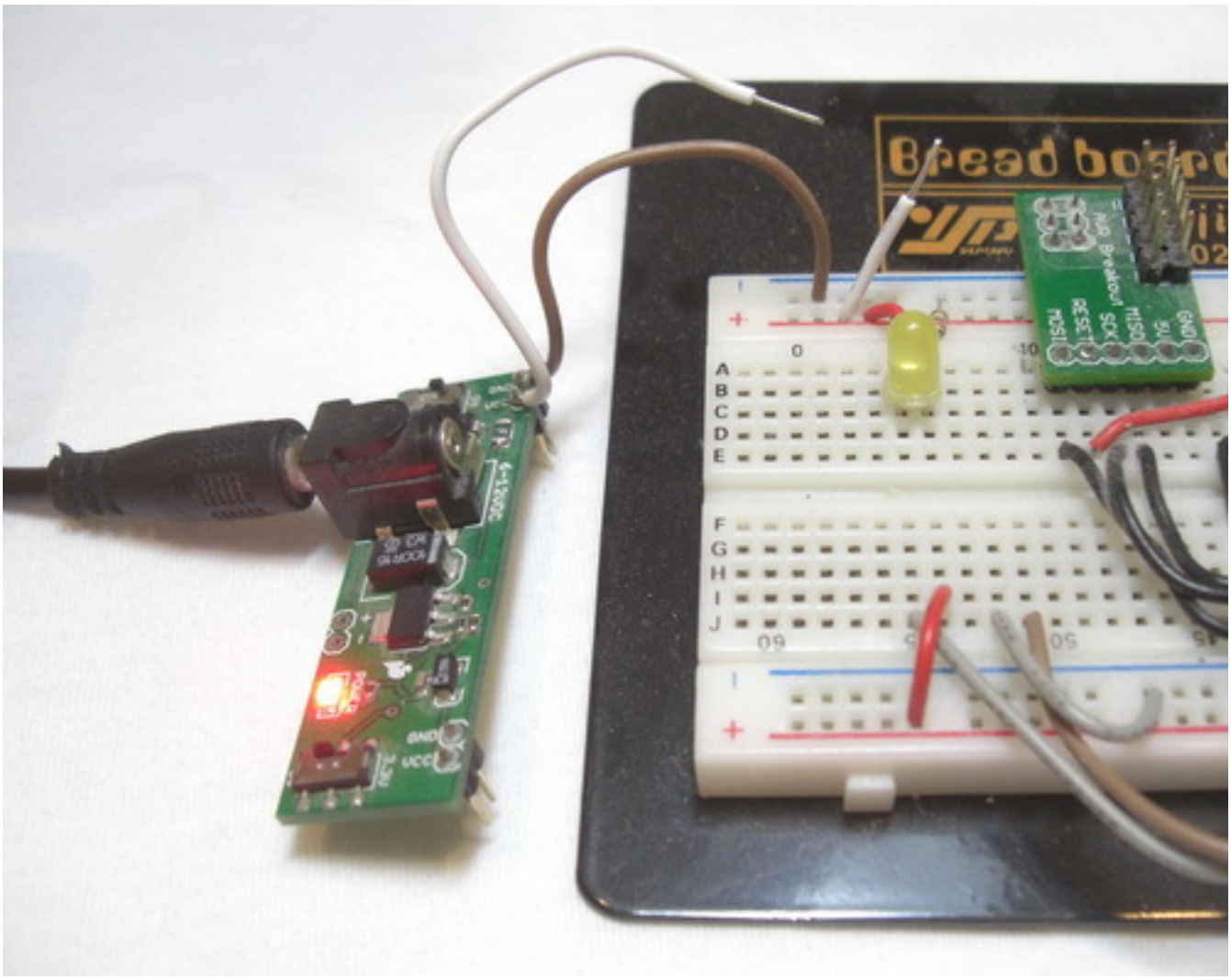
Let's say you go into 2kΩ mode and the multimeter reads "0.329" (0.33 of the 1,000 setting is 330), then you probably have a 330Ω resistor commonly used to limit current into LEDs. Remember that measuring resistance is not perfect. Temperature can affect the reading a lot. Also, measuring resistance of a device while it is physically installed in a circuit can be very tricky. The surrounding components on a circuit board can greatly affect the reading.

How to Measure Current

Reading current is one of the trickiest and most insightful readings in our world of embedded electronics. It's tricky because you have to measure current in series. Where voltage is measure by poking at VCC and GND (in parallel), to measure current you have to physically interrupt the flow of current and put the meter in line. Said another way, pull out the VCC wire going to the breadboard and then probe from the power pin on the power supply to the VCC rail on the breadboard.

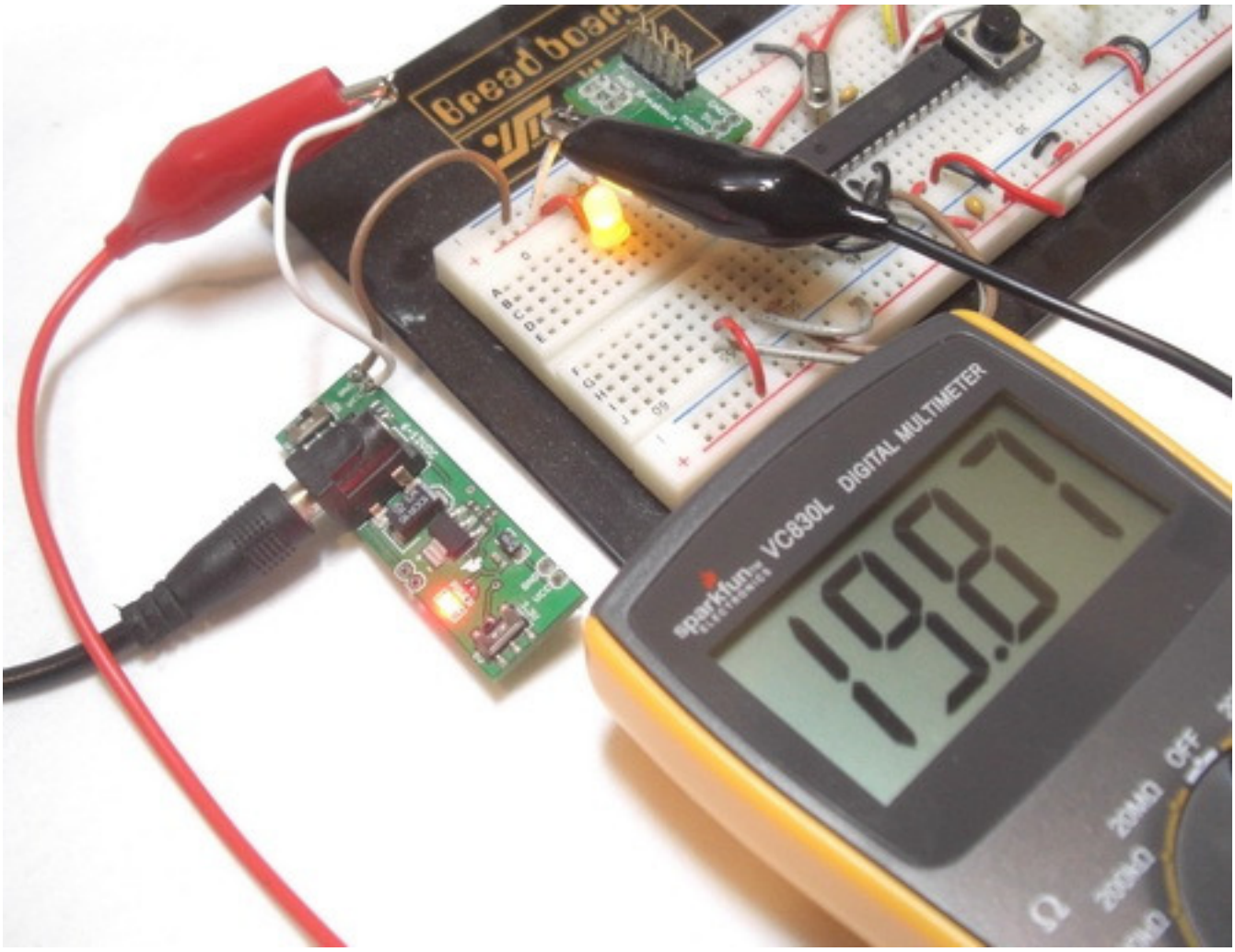


and then...



The current consumption in most of my projects is under 200mA. I run pretty small systems. So let's say you want to measure an ATmega328 with a blinking LED. Make sure the red probe is plugged into the 200mA fused setting. On my favorite multimeter (I'm not just saying that, I really do have/use one at home and work) the 200mA hole is the same port/hole as voltage and resistance reading (the port is labeled **mAVΩ**). This means you can keep the red probe in the same port to measure current, voltage, or resistance. Just remember: you have to measure current in series, not parallel.

The current mode works the same as voltage and resistance - you have to get the correct range. So set the multimeter to 200mA. In the image above, I've pulled the wire out of the VCC pin on the bread board power supply and added another wire to the VCC rail. This way I can more easily connect the red probe to the wire coming out of the power supply, and the black probe to the wire sticking out of the bread board. This effectively "breaks" power to the breadboard. We then insert the multimeter inline so that it can measure the current as it "flows" through to the multimeter into the bread board.

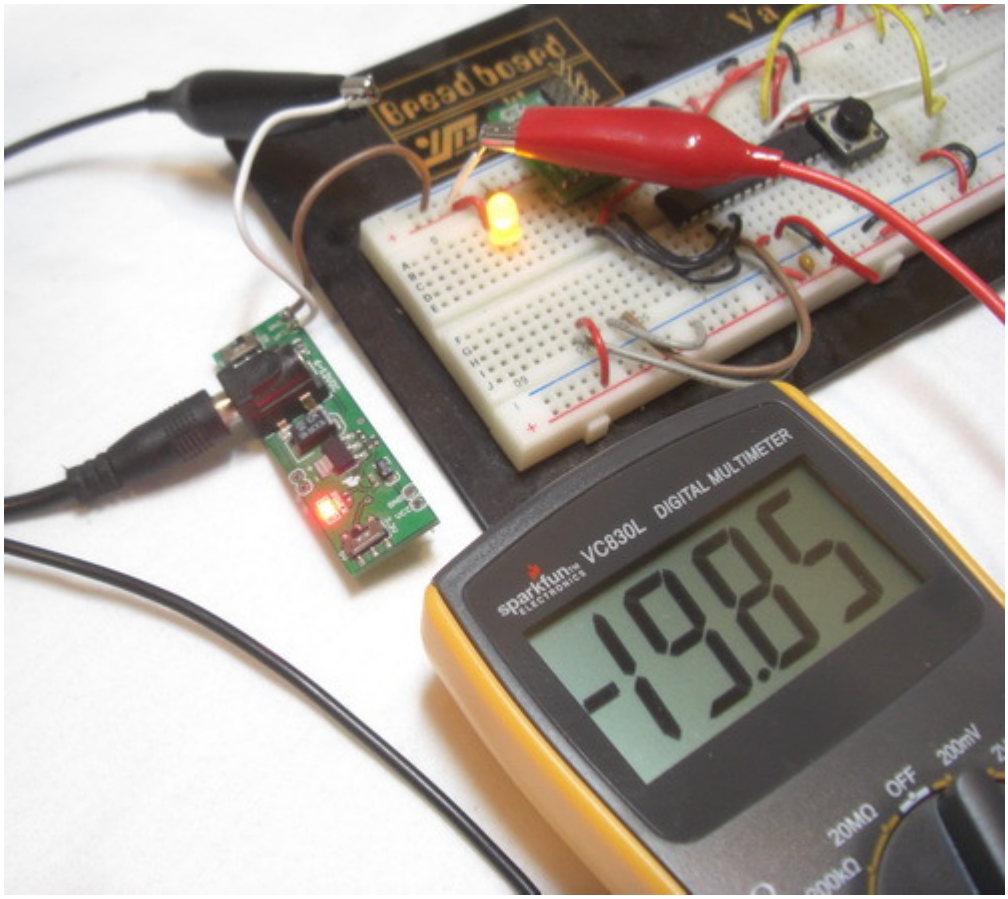


Now connect the red probe to the VCC pin on the power supply, and the black pin to the VCC rail on the bread board. Realize that the multimeter is like a piece of wire - you've now completed the circuit and the breadboard is now energized (and will start running). This is important because as time goes on the microcontroller, or sensor, or device being measured may change its power consumption (such as turning on an LED can resulting in a 20mA increase for a second, then decrease for a second, etc). On the multimeter display you should see the instantaneous current reading. All multimeters take readings over time and then give you the average so expect the reading to fluctuate. In general, cheaper meters will average more harshly and respond more slowly, so take each reading with a grain of salt. I generally look for a range, such as 7 to 8mA under normal 5V conditions (not 7.48mA). To give you a rough idea of power consumption: 8mA (0.008A) on a 5V system is incredibly small (0.040W). A light bulb will easily consume 40W, or 1,000 times more energy.

For the pictures above I cheated and used alligator clips. When measuring current, it's often good to watch what your system does over time, a few seconds or minutes. While you might want to stand there and hold the probes to the system, I'm lazy. So these alligator clip probes come in handy. Note that almost all multimeters have the same sized

jacks (they're called "banana plugs") so if you're in a pinch, you can steal your friend's probes.

Similarly, when measuring current the color of the probes does not matter. What happens if we switch probes? Nothing bad happens! It simply causes the current reading to become negative:



Current is still flowing through the system, you've just changed your perspective and now the meter reads negative.

Remember: When you're done using the meter, always return the meter to read voltage (return the probes to the voltage port, set the meter to read the DC voltage range if necessary). I often pick up the meter quickly and without checking what setting the meter is in, I attempt to measure voltage on a circuit. When the reading comes up as '0.00', I realize I have left the probe in the 10A port 2 weeks ago (when I used the meter last) and I am shorting VCC and Ground. Not good. So before you put the meter down for the night, remember to leave your meter in a friendly state.

Changing the Fuse

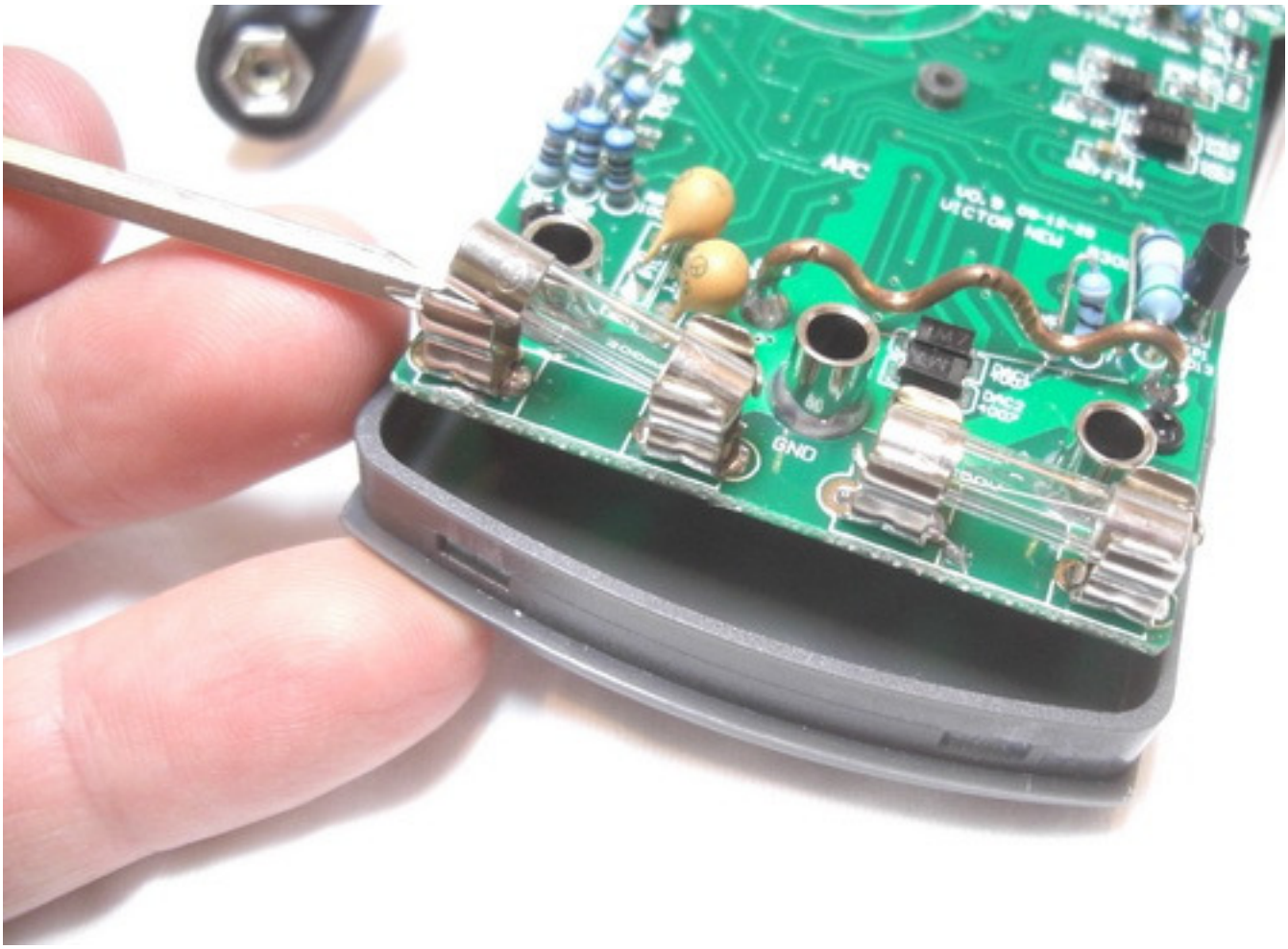
When I first started in electronics back in 2002, one of the first things I did with my brand new multimeter was to measure current on my bread board by probing from VCC to GND (bad!). This will immediately short power to ground through the multimeter causing the bread board power supply to brown out. As the current rushed through my multimeter, the internal fuse heated up and then burned out as 200mA flowed through it. It all happened in a split second and without any real audible or physical indication that something was wrong. Wow, that was neat. Now what? Well first, remember that measuring current is done in series (interrupt the VCC line to the breadboard or microcontroller to measure current). If you try to measure the current with a blown fuse, you'll probably notice that the meter reads '0.00' and the system doesn't turn on when you attach the multimeter like it should. This is because the internal fuse is broken and acts as a broken wire. Don't worry, I do this all the time and it costs about $1 to fix.

Find your handy dandy mini screw driver and start taking out screws. The SparkFun DMM is pretty easy to pull apart.

Lift the face of the multimeter slightly.

Now notice the hooks on the bottom edge of the face. You will need to slide the face sideways with a little force to disengage these hooks.

Once the face is unhooked, it should come out easily. Now you can see inside the multimeter!



Lift gently up on the fuse and it will pop out. Make sure to replace the correct fuse with the correct type. In other words, replace the 200mA fuse with a 200mA fuse. Do not put a 10A fuse where a 200mA fuse should go. The components and PCB traces inside the multimeter are designed to take different amounts of current. You will damage and possibly vaporize traces if you accidentally push 5A through the 200mA port.

There are times where you need to measure high current devices like a motor or heating element. Do you see the two places to put the red probe on the front of the multimeter? **10A** on the left and **mAVΩ** on the right? If you try to measure more than 200mA on the **mAVΩ** port you run the risk of blowing the fuse. But if you use the 10A port to measure current, you run a much lower risk of blowing the fuse. The trade-off is sensitivity. As we talked about above, by using the 10A port and knob setting, you will only be able to read down to 0.01A or 10mA. Most of my systems use more than 10mA so the 10A setting and port works well enough. If you're trying to measure very low power (micro or nano amps) the 200mA port with the 2mA, 200uA, or 20uA could be what you need.

Remember: If your system has the potential to use more than 100mA you should start with the red probe plugged into the **10A** port and **10A** knob setting.

With sub $50 digital multimeters, the accuracy is not extremely high. The measurements you are likely to take are just trouble shooting readings, not scientific experimental results. If you really need to see how the IC uses current or voltage over time, use an Agilent or other high quality bench unit. These units have higher precision and offer a wide range of fancy functions (some include Tetris!). Bunnie Huang of Chumby uses high-precision current readings to trouble shoot boards during the final testing procedures of a Chumby. By looking at the current consumption of different boards that have failed (for example a given failed board uses 210mA over the normal), he could identify what was wrong with the board (when the RAM fails, it generally uses 210mA over normal). By pinpointing what may be potentially wrong, the rework and repair of boards makes his job much easier.

Continuity Is Your Friend

Continuity is the reason I carry a multimeter wherever I go. It is the single most important function for embedded hardware gurus. Set the multimeter to 'Continuity' mode. It may vary from DMM to DMM, but look for a diode symbol with propagation waves around it (like sound coming from a speaker).

Now touch the probes together. The multimeter should emit a tone (**note:** Not all multimeters have a continuity setting. Only the cool ones do). This shows that a very small amount of current is allowed to flow without resistance (or at least a very very small resistance) between probes. Use the probes to poke at the ground pins on a breadboard, you should hear a tone indicating that they are connected. Poke the probes from the VCC pin on a microcontroller to VCC on your power supply. It should emit a tone indicating that power is free to flow from the VCC pin to the micro. If it does not emit a tone, then you can begin to trace the route that net takes and tell if there are breaks in the line, wire, breadboard, or breaks on the PCB trace.

I often use continuity to test if two SMD pins are touching. If my eyes can't see it, the multimeter is usually a great second testing resource.

When a system is not working, continuity is one more thing to help trouble shoot the system. Here are the steps I take:

1. If the system is on, carefully check VCC and GND to make sure the voltage is the correct level. If the 5V system is running at 4.2V check your regulator carefully, it could be very hot indicating the system is pulling too much current.
2. Power the system down and check continuity between VCC and GND. If there is continuity (you hear a beep when poking '+' and '-'), then you've got a short some where.
3. Power the system down and with continuity, check that VCC and GND are correctly wired to the pins on the microcontroller and other devices. The system may be powering up, but the individual ICs may be wired wrong.
4. Assuming you can get the microcontroller running, set the multimeter aside and move on to serial debugging or use a logic analyzer to inspect the digital signals.

Remember: In general, turn OFF the system before checking for continuity.

Continuity and large capacitors: On many of my systems, I will probe for continuity between ground and the VCC rail. This is a good sanity check before powering up a prototype to make sure there is not a short on the power system. But don't be surprised if you hear a short 'beep!' when probing. This is because there is often significant amounts of capacitance on the power system. The multimeter is looking for very low resistance to see if two points are connected. Capacitors will act like a short for a split second until they fill up with energy, and then act like an open connection. Therefore, you will hear a short beep and then nothing. That's ok, it's just the caps charging up.

What makes a good multimeter?

Everyone has his or her preference, but in general I prefer multimeters that have continuity. Every other feature is just icing on the cake.

Auto-ranging can be very helpful if you know how to use it. Generally speaking, autoranging multimeters are higher quality and generally have more features. So if someone gives you a multimeter with auto-range, put it to use! Just know how to get it into manual mode. With some of the systems I'm measuring, the current or voltage is so sporadic that the auto-range can't keep up sensibly.

A back-lit LCD is fancy, but when was the last time you measured your circuit in the dark? I haven't, but some people may want or need a dark-friendly multimeter.

A good click on the range selector is actually a major plus in my book. A soft knob is usually indicative of a shoddy meter.

Decent probes are a plus. Over time the leads will tend to break down at the flex point. I've seen wires come completely out of probes - and it's always at the moment you need the probes to work! If you do break a probe, they are reasonably cheap to replace. We sell them for $4 over here.

Auto-off is a great feature that is rarely seen on cheaper multimeters. I really like this feature as I often forget to turn my meter off at 2AM. The SparkFun digital multimeter doesn't have this feature, but luckily the meter is fairly low-power. We've left the multimeter for two days straight before the 9V battery began to get low. That said, don't forget to turn your meter off!

Remember that this tutorial is just the minimum basics to get you up and running with a basic multimeter. If you want to learn more advanced techniques, be sure to google for more information.

Enjoy!